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Operational characteristics of a pressurised Van de Graaff generator

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Detailed investigations on the operational characteristics of a pressurised Van de Graaff Generator were undertaken The input and transfer characteristics, distribution of currents, and the terminal voltage and its load characteristics were studied at different nitrogen gas pressures upto 75lb/in^2 g

1. Introduction

Van de Graaff generators are expensively used for precision experiments innuclear physics Some operational characteristics of such generators under atmospheric conditions are available in the literature through the pioneering works of R. J. Van de Graaff and his associates (Van Atta *et al* 1936) and of J F. Smee (Smee 1944) However, no such detailed study under pressurised condition has been reported in the literature (Herb *et al* 1937, Trump & Van de Graaff 1939, Van de Graaff *et al* 1946, Craggs & Meek 1954, Herb 1959, Livingston & Blewett 1962, Trump 1964) We, therefore, undertook intensive studies on the operational characteristics of a pressurised Van de Graaff generator in the one million volt range, which has been designed and constructed utilizing indigenously available materials and local engineering fabrication facilities (Chatterjee *et al* 1973), for a better understanding of its operation Some of the results obtained from these experiments have been briefly reported elsewhere (Ganguly & Saha 1973)

2. Experimental Setup and Procedures

The Van de Graaff generator (Chatterjee *et al* 1973) used in our experiment is a horizontal machine housed inside a pressure vessel having an overall dimension of about 3 ft dia $\times$ 5 ft long Perspex was used as the insulating support structure material for the high voltage terminal made of spun aluminium The terminal itself was a 22″ dia cylinder ending as a hemisphere of radius 11″ at the top terminal end, its total length being 22″. The gap between the two coaxial cylinders, viz., the high voltage terminal and the grounded pressure vessel was about $5\frac{1}{4}$″ on the sides. The pressure vessel was first evacuated to better than 10^{-2}mm of Hg to remove traces of moisture before filling it with commercial

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quality nitrogen gas (water vapour content ~ 600 ppm) obtained in cylinders from M/s. Indian Oxygen Ltd. The mean room temperature during the experiments was ~ 28°C.

A 18 cm wide × 3 mm thick endless nylon-woven charge transport belt mounted on two 3″ dia solid mild steel rollers, one each at ground and high voltage ends, was driven by a 3 phase 2 H.P. motor at a linear speed of 1300 metres/min. Corona combs for the spraying and collection of charges were made from $\frac{1}{2}$″ long gramophone needles fixed on a $\frac{1}{2}$″ dia brass rod, the distance between two adjacent needles being $\frac{1}{4}$″. The relative performances of different comb configurations and their geometries for transport of charges to the high voltage terminal have been studied earlier under atmospheric conditions (Ganguly & Saha 1975). For studies under pressurised nitrogen gas we have used the arrangement of combs shown in figure 1 which was found to be the most convenient one under atmospheric conditions (Configuration IV 2a of Ganguly & Saha 1975)

The terminal voltage was measured by a generating volt-meter. Its response was found to be linear above 15 kV and was practically independent of pressure and the type of the filling gas. The load current I_{CN} from the high voltage terminal was drawn with the help of an adjustable corona needle assembly which was grounded through a current measuring meter. The gap between the corona needle tip and the dome was varied to control the terminal voltage. When the corona needle touches the dome, the current flowing through it is the short circuit current I_S

The relation between different currents under short circuit condition, shown in figure 1, are as follows

$$I_C = I_+ + I_{LC} \quad \text{.. (1)}$$

and

$$I_S = I_+ + I_- \quad \text{.. (2)}$$

From these equations we can write

$$I_+ = I_S - I_- \quad \text{... (3)}$$

and

$$I_{LC} = I_C - I_+ = I_C + I_- - I_S \quad \text{... (4)}$$

Thus, I_+ and I_{LC} were estimated from the measured values of I_C, I_S and I_- under short circuit condition. Also, the resultant input current at the ground end

$$I_{in} = I_c + I_- \quad \text{... (5)}$$

and hence can be calculated from the measured values of I_C and I_-.

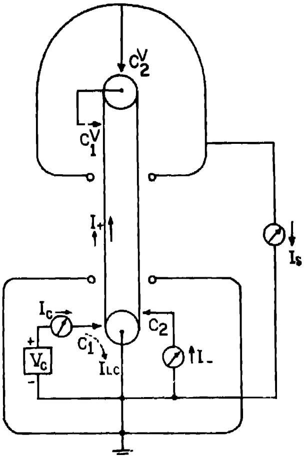

Fig. 1. Schematic diagram showing the distribution of currents under short circuit condition (Configuration IV 2a of Ganguly & Saha 1975).

C_1, C_2 : ground end corona combs; V_C : ground end spray voltage; I_C : ground end spray current; I_+ : current due to positive charges going up with the belt; I_- : current due to negative charges coming down with the belt and collected by the comb C_2; I_{LC} : leakage current at the ground end; C_1^v, C_2^v : corona combs inside the dome; I_S : short circuit current

Distance of the ground end roller centreline from the ground end base plate $d_R = 2\frac{1}{2}''$, distances of the combs C_1, C_2 from the ground end roller centreline $d_{CR1} = \frac{1}{2}''$, $d_{CR2} = 2''$ respectively; distance of the dome end roller centreline from the dome base plate $d_R^v = 2\frac{1}{4}''$; distance of the comb C_1^v from the dome base plate $d_{C_1}^v = 1\frac{1}{4}''$, static gaps between the belt and needle tips of the combs C_1, C_2, C_1^v C_2^v : $g_1 = g_2 = g_1^v = g_2^v = 3/8''$.

3. Results and Discussions

The plot of ground end spray current I_C against spray voltage V_c is an input characteristic of the generator. A typical plot of I_C vs V_C along with the corresponding ground end spraying efficiency I_+/I_c at a nitrogen gas pressure of 3 atmospheres absolute are shown in figure 2(a) The spray current increases with the spray voltage The initial slow rise is due to leakages The abrupt rise in I_C from $V_C \sim 19\,\mathrm{kV}$ coincides with the threshold of spraying efficiency marking the onset of charge spraying through corona. From here the increase in the spray current and the spraying efficiency is due to the increase in charge density on the belt The spraying efficiency reaches a peak at $V_C \sim 25$kV indicating a saturation in the charge density Subsequent increase in I_C along with the decrease in spraying efficiency indicates the onset of leakage of charges in excess of saturation

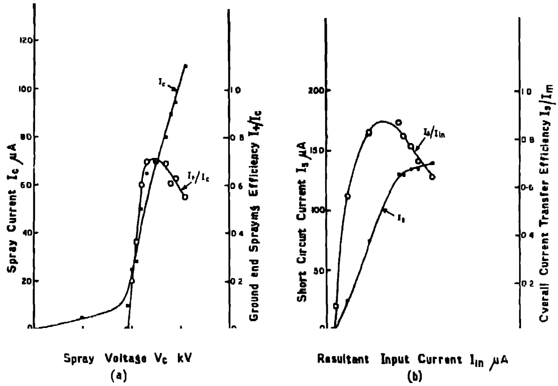

Fig. 2(a) Variation of ground end spray current I_C and the ground end spraying efficiency I_t/I_C with the spray voltage V_C at a nitrogen gas pressure of 3 atmospheres absolute.

Fig. 2(b) Dependence of short circuit current I_S and over all charge transfer efficiency I_S/I_{in} on the resultant input current at the ground end I_{in} at a nitrogen gas pressure of 2 atmospheres absolute.

from the surface of the belt. Input characteristic curves of similar nature have been found for pressures upto 6 atmospheres nitrogen The threshold for corona was found to increase linearly with gas pressure—a characteristic feature of the gas breakdown phenomena. The peak ground end spraying efficiency was found to remain constant to a value $\sim$70% irrespective of the pressure of nitrogen gas upto 6 atmospheres absolute.

The dependence of the short circuit current I_S on the resultant input current I_{in} represents a transfer characteristic of the Van de Graaff generator. The variation of short circuit current I_S and the overall charge transfer efficiency I_S/I_{in} with the resultant input current I_{in} were investigated at different nitrogen gas pressures upto 6 atmospheres absolute. A typical plot of I_S and I_S/I_{in} vs I_{in} for 2 atmospheres nitrogen are shown in figure 2(b). The characteristics are similar for different pressures The maximum overall charge transfer efficiency remains well above 80% and is practically pressure independent indicating that our generator is a low current loss system.

The variation of the short circuit current I_S, current due to positive charges going up I_+, current due to negative charges coming down I_-, and the leakage current at the ground end I_{LC} as a function of spray current I_C were studied at different nitrogen gas pressures under short circuit condition A typical plot for 3 atm. N_2 is shown in figure 3(a). The currents I_S, I_+ and I_- all show satura-

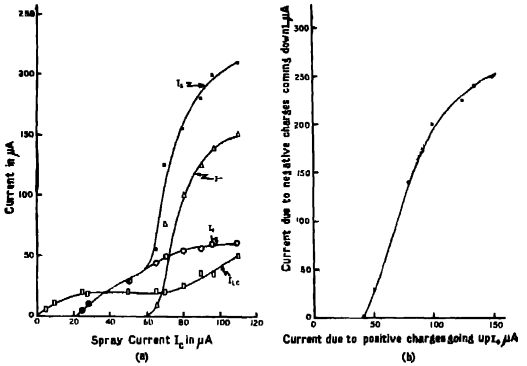

Fig. 3(a) Variation of different currents with the ground end spray current I_C at a nitrogen gas pressure of 3 atmpsheres absolute.

Fig. 3(b) Dependence of current due to negative charges coming down I_- on the current due to positive charges going up I_+ at a nitrogen gas pressure of 5 atmospheres absolute.

tion with I_C The leakage current I_{LC} increases rapidly after saturation in I_+ is attained. The linear increase in the saturation values of I_S, I_+ and I_- with nitrogen gas pressure is shown in figure 4 The systematic difference in the saturation values of I_+ and I_- is inferred to be due to different sticking probabilities of different types of ions onto the charge transport belt

The dependence of the current due to negative charges coming down I_- on the current due to positive charges going up I_+ was studied at different nitrogen gas pressures A typical curve for 5 atm. N_2 is shown in figure 3(b) There is a threshold value of I_+ from where I_- starts. Further, I_- ultimately shows saturation with I_+ due to saturation in the negative charge density on the belt At a particular pressure, this thershold value of I_+ is the minimum amount of upgoing positive charge current that is necessary to produce the required roller to dome voltage for negative charge spraying to commence The threshold value of I_+ was found to increase linearly with nitrogen gas pressure.

The maximum steady terminal voltages attained in our Van de Graaff generator at different nitrogen gas pressures are shown in figure 4 A maximum terminal voltage of 1.1 million volt was achieved at 75 lb/in^2 g nitrogengaspressure with a spray voltage of 38 kV. The load characteristics of the generator at different nitrogen gas pressures are shown in figure 5. The curves reveal the essentially constant current feature of the generator.

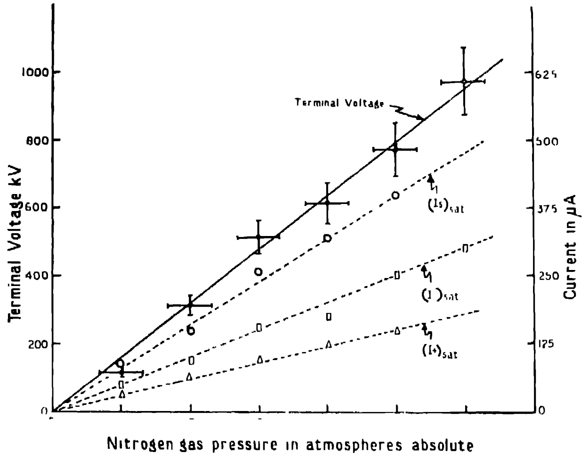

Fig. 4. Dependence of terminal voltage and the saturation values of the currents I_S, I_+ and I_- on nitrogen gas pressure

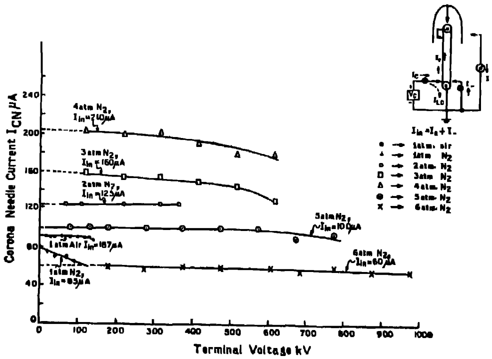

Fig. 5. Load characteristics of the Van de Graaff generator at different gas pressures.

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